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SUMMARY

The design and start of operation of a solid homogeneous zero power reactor, ZR-4, is described which has been intended for experimental work in connection with reactor kinetics and the verification of reactor physics calculations.

The small, approximately cubical core consists of polyethylene-U_3O_8 blocks and is reflected by layers of graphite and paraffine. The system is equipped with an advanced, self-checking safety and interlock system using pulse and DC channels for flux level monitority and absorber plates between the core and the reflector as control elements. In the first part of the paper details of the mechanical construction and of the electronic circuits are given.

In later sections the results of routine experiments performed before normal operation of ZR-4 commenced are summarized. Critical mass, flux distributions, reactivity worths, temperature coefficients, kinetic parameters and radiation measurements are mentioned.

РЕЗЮМЕ

Сообщаем рутинные измерения, связанные с конструкционным устройством и пуском реактора нулевой мощности с твёрдогомогенной зоной, типа ЗР-4.
Это устройство создали с целью контрольных экспериментов в области кинетики и реакторнофизических измерений.
Активная зона приблизительно кубической формы, состоит из блоков смеси полиэтилена и U_3O_8, окруженная графитовым и парафинным отражателем.
К установке принадлежит современная самоконтролирующая аварийная и регулирующая система электроники, в которой для измерения потока нейтронов, служит импульсные каналы и каналы постоянного тока, а регулирование величины реактивности осуществляется с перемещением поглащающих пластин, расположенных на границе активной зоны и отражателя.
В первых пунктах были даны сообщения о сооружении сборки.
В дальнейших пунктах занимаемся рутинными измерениями, которые были завершены при пуске сборки, с целью определения характерных параметров.
В этих пунктах приведены результаты измерений по критической массе, распределению потока нейтронов, весам и ценам (по реактивности), температурным коэффициентам, кинетическим параметрам и дозиметрии.

KIVONAT

A ZR-4 jelü, szilárd-homogén zónáju zero-reaktor szerkezeti felépitését és az üzembehelyezésével kapcsolatos rutin méréseket mutatjuk be. A berendezést kinetikai kisérletek és reaktorfizikai számitások ellenőrző kisérletei céljára létesitettük.

Az aktiv zóna polietilén - U_3O_8 blokkokból áll, közelitőleg kocka alaku és körben grafittal és paraffinnal van reflektálva. Modern, önvizsgáló biztonsági és szabályozó elektronika tartozik hozzá, amelyben a fluxus monitorozására impulzusláncok és egyenáramu láncok foglalnak helyet, a reaktivitás szabályozása pedig a zóna és a reflektor között mozgatható abszorbens lemezekkel történik. Az első néhány pontban a rendszer felépitését ismertetjük.

A további pontokban foglalkozunk azokkal a rutin mérésekkel, amelyeket a berendezés üzembehelyzése során végeztünk a jellemző paraméterek kisérleti meghatározása céljából. Itt kritikus tömeg, fluxus eloszlás, reaktivitás értékességek, hőmérsékleti tényező, kinetikai paraméterek mérését és sugárvédelmi méréseket emlitünk.

1. INTRODUCTION

The zero power reactor ZR-4 was built in 1966 in the Reactor Laboratory of the Central Research Institute for Physics. This reactor was designed and constructed by the laboratory staff.

The two main directions of the research program planned for the reactor ZR-4 are:

1./ The experimental test of reactor-physics calculations.
2./ Studies in reactor-kinetics.

When choosing the type of the reactor these objectives played a decisive part and justified a decision involving an active zone with the most simple geometry possible and free of perturbations. On the basis of these considerations a solid-homogeneous system with graphite reflector was chosen. The mechanical construction is very simple in the interest of flexibility.

Although the reactor ZR-4 was built for research purposes, it seems, according to our experiences, to be very suitable, - owing to its simplicity, inexpensiveness and high inherent safety - for the use as a training reactor as well.

2. DESCRIPTION OF THE ZR-4 REACTOR

As it is well known many solid-homogeneous reactors have been built, mainly for educational purposes /AGN-201 [1] AGN-211 [2] , SUR-100 [3]/.

The composition of the fuel of ZR-4 is similar to these systems, but owing to the construction of the fuel element the reactor is more flexible and makes many more kinds of experiment possible.

2.1 Characteristics of ZR-4

General

Type	Homogeneous thermal reactor
Maximum power	10 W
Core	Solid blocks of U_3O_8 /20% enriched in U^{235}/ and polyethylene homogeneous mixture

Reflector	Graphite
Shield	Lead, paraffine, heavy concrete
<u>Fuel</u>	
Fuel material	20% enriched U_3O_8, 60 mg U^{235}/cm^3
Shape of element	5x5x65 cm, containing a top and a bottom graphite of 15 cm length each. The central active part consists of 3 uranium-polyethylene blocks of 10 cm each and a 5 cm long lead shield on the top. The components are fastened together by an aluminium frame
Overall active core	~ 20x25x30 cm
Moderator	polyethylene
<u>Control elements</u>	Four aluminium covered cadmium plates /two safety, one shim, one automatic control/

2.2 The Fuel Blocks

Each fuel element contains three uranium-polyethylene blocks of 5x5x10 cm /Fig. 1/, designed and manufactured in the Institute. The phases of the block fabrication procedure were:

1/ Mixing and fusing of the polyethylene and uraniumoxide powders.
2/ Pressing.
3/ Coating.

U_3O_8 powder enriched to 20% in U^{235} imported from the Soviet Union and low pressure polyethylene were used for the production of the blocks. Coating was made by high pressure polyethylene dissolved in an organic solvent.

The blocks were checked for dimension and weight and examined by X-ray test. Irregularities were eliminated by re-pressing.

Before starting with the production of the fuel blocks the health physics and nuclear safety problems of the production and the storage have been investigated in detail. Regulations ensuring safe work have been worked out on the basis of this investigation.

3. MAIN TECHNICAL CHARACTERISTICS

3.1 The Construction of the Core

In the basic geometry the fuel elements are arranged by fives in four rows separated by air gaps of 2 mm due to the aluminium angular profiles /Figs. 2.3/. The core is surrounded by a 20 cm thick graphite reflector, assembled of individual prisms, with a height equal to the length of the fuel elements. The base of the core and the reflector is a highly reinforced flat box.

3.2 Control Elements

On two sides of the core gap is provided for the control plates moving in protecting sheaths. Dimensions of the cadmium plates:

Shim and automatic control plates:	50x50x0,1 cm
Safety "	10x50x0,1 cm

All the four control elements are actuated by servo-mechanisms designed and manufactured in the Institute.

When the reactor has been scrammed by any scram signal, the two safety rods drop into the reactor, while the two others are automatically driven into their lowest positions by the servo-mechanism. The falling time of the safety rods is about 0,5 sec.

3.3 Shielding

The core and the graphite reflector are surrounded underneath by paraffine shielding with a thickness of 20 cm, and on the sides by paraffine brickes with dimensions of 10x20x30 cm. The upper shielding consists of a 30 cm thick paraffine layer over the reflector and a 30 cm thick removable lucite block over the core.

The reactor hall has concrete walls of 1 m thickness, therefore no additional shielding is necessary, but during operation personnel must not enter the hall.

In the interest of an improved biological shielding steel cased wall elements - which may be put up in any required form - made of 45 cm thick heavy concrete bricks were also constructed. The 4 protecting walls provided with handrails and stairs give the reactor a cubic form of 2 m sidelength.

4. INSTRUMENTATION

During the construction of the ZR-4 reactor there was great emphasis upon the principle that the reactor should be suitable for carrying out research work also in the field of reactor automation. This was one of the main reasons why a rather sophisticated instrumentation, safety and interlock system was constructed and has been subjected to continuous development.

4.1 Measuring Channels and Control Elements

The safety and interlock system of the reactor is informed about the nuclear state of the core by seven independent measuring channels [4], as shown in Fig. 4. Two pulse channels and four DC channels /two of them are operated on logarithmic scale and are equipped with both upper limit and period trips/ belong to the safety system, and one more DC channel is reserved for the automatic power level control.

The positions of the neutron detectors can be seen in Fig. 3. The pulse detectors are a BF_3-counter /type SNMO-5/ and a fission chamber /20th Century Electronics FC3/1000/, the five DC channels are ionization chambers /type KNT-53 and KNK-56/. The detectors are protected by boxes which together with the detector casings form rugged units. Each pulse channel is built from highly reliable, fully solid state modular units, developed in the Institute.

The main amplifiers and the other units are mounted in international standard rack and are installed near the control desk. The details about the pulse channels are given in another paper [5].

The counting rate meter units are supplied with remote control facility, which offers much comfort to the operator during reactor start-up. The output signals of the counting rate meters are fed into the safety circuits and to pointer instruments, as shown in Fig. 4.

It is especially useful during reactor start-up that the operator is kept informed also acoustically about the actual power level of the reactor by the "acoustic pulse rate indicator". This consists of a six decade pulse counter and of an audio-frequency unit. The latter can be connected, with the aid of push-buttons on the central control desk, to any of the decades of the pulse counter. The pushbutton in "on" state determines at the same time the frequency of the A.F. carrier signal.

A pulse counter with print-out facility is provided for performing some typical measurements and tests on the reactor while operating. This counter is controlled by another one, the latter featuring both preset time and preset count facilities. The counting facilities are provided by a multipurpose digital instrument /"DORA"/ the use of which as a digital reactor period meter was explained in a paper presented during the Budapest Reactor Conference [6].

The reactor power is also measured by four DC channels which operate from compensated and not-compensated ionization chambers. The amplifiers used now work with vacuum tubes but they will be replaced by solid state ones, described in detail in reference [5]. In the period protection circuits and in the automatic power level control system some special units are used and they are explained in detail in paper [7]. The drive units for the motors of the control elements are described also in paper [7]. The description of the preoperational testing instrument is given also there.

4.2 <u>Safety and Interlock System</u>

The safety and interlock system of the ZR-4 reactor is a self-checking one which connects the measuring channels, the actuating elements and the commands of the operator into a unified scheme. Having several years of practice with relay safety systems, this choice was motivated by the expected technical advantages of high reliability, long life and lack of electrical noises, as well as by the aim of obtaining a research tool for gaining experience in the design, construction and operation of up-to-date complex semiconductor logic systems used for reactor control purposes.

Since the circuitry of the system, as developed in the Institute, is published in the literature [8], while some of the theoretical aspects of the design are treated in another paper [9], we shall restrict ourselves to the presentation of some general considerations about the system in question. The whole logic system consists essentially of two parts: the fundamental static logic system and the checking system coupled dynamically to the former.

The basic aim of the design was to achieve a noise-free and highly reliable system. The choice of semiconductor switching networks obviously results in the elimination of internal noises induced by sparks at the contacts of relay systems, the effect of external electrical noises was reduced to a great extent by the selection of a logic system with a relatively low cut-off frequency /EDS 4000, STATOMAT series of the EMG factory, Budapest, with a cut-off frequency of 2 kHz and with a rugged construction for industrial applications/ and in which the long life attributed to semiconductor logic elements is ensured by careful design. However, even this relatively low speed of the logic elements chosen offers the possibility of further improvement as to the system reliability by the application of self-checking.

The checking principle used here is well known and is based on the fact that when short pulses of some millisecond duration are sent through the logic system from its input to the actuating elements, they do not change the operational state of the actuating element /e.g. an energized magnet remains energized if a scram command of some millisecond duration is applied to its coil/ but an electronic indication can be obtained about the working ability of the whole logic channel in question. These indications are used as warning signals, or they release reactor scrams in some cases at the ZR-4 reactor.

Though the addition of the checking system increases the number of circuit components in the whole logic, the overall reliability is nevertheless improved to a great extent because of the system engineering solution chosen here. The dynamic coupling ensures that no failure of the checking system influences the correct operation of the fundamental logic, however any failure in the fundamental logic cannot remain undetected for a longer time than the testing cycle, even if it is an unsafe failure. As a result, the complex system will be more reliable and the operating personnel is informed - or even the counteraction is automatically carried out - wether the fundamental logic is able to perform the interlock and safety tasks attributed to it.

4.3 Experiences and Further Developments

On the basis of more than two years of operation we can conclude that the system has worked as reliably as expected at the design stage. In the early operational period the power transistors of the power amplifiers energizing the magnets broke down in 3 cases but they were always detected by the self-checking system. It is of interest to mention that these transistors failed in short circuited way which could have been very dangerous if not detected. It is intended to change the germanium power transistors for more reliable silicon devices. In the operational period one inverter and one trigger circuit failed, but they were also detected.

From experimental purposes in connection with the construction of the Training Reactor of the Technical University of Budapest the checking frequency was increased from 1 Hz to about 50 Hz and the self-checking is restricted to the safety system only.

For the DC channels - as mentioned earlier - a vacuum tube amplifier system was applied. As the reliability of this did not prove sufficient because of microphonic sensitivity and thermal drifts due to high power consumption, it was decided to substitute the vacuum tube amplifiers by fully semiconductor DC amplifying modules, developed recently in the Institute.

5. EXPERIMENTAL INVESTIGATION

5.1 Critical Mass

The reactor ZR-4 went critical the first time on May 7, 1966. The basic geometry, which gives a critical mass of 850 grams, requires a 4x5 array of fully loaded elements excepting the D5 element, which contains only one fuel block.

In Table 1. the critical masses of similar reactors are given.

Table 1

Comparison of critical masses

Type of reactor	*Crit. mass. grams*
AGN-201	*664*
AGN-211	*780*
SUR-100	
ZR-4	*850 (720)* x/

x/ *Tightly packed core*

The relatively high critical mass of ZR-4 is the consequence of two effects. The neutron leakage through the air gaps between the fuel elements is high, and the cubical geometry is worse than the cylindrical one. To investigate the neutron leakage a critical experiment was carried out by tightly packed fuel elements eliminating the gaps. The critical mass decreased to 720 grams in a 4x4 array plus one fuel block in the C5 position, showing that the leakage effect is very high.

The design of the reactor was started by preliminary calculations carried out using one dimensional two group diffusion equations. The results are summarized in Table 2.

Table 2

The nominal parameters of the core

$mg\ U^{235}/cm^3$	70	60	50
$H/U\text{-}235$	428	503	608
$n \cdot f$	1.68	1.64	1.57
k_∞	1.61	1.57	1.51
G_{krit} unreflected gr	2165	2028	1946
G_{krit} reflected gr		910	

5.2 Thermal Flux Distribution and Buckling

For the thermal flux distribution measurements Al wires with 10% Dy content and Au-Au/Cd/ foils were used. The activity distribution along the wire was measured by the standard automatic technique developed at the Laboratory. The positions of the wires in the core can be seen in Fig. 3. Some of the measured flux distributions are shown in Figs. 5 to 8. The distributions measured in three perpendicular directions were fitted by circular functions. In this way the buckling values could be determined.

The axial flux distribution measured on the surface of the fuel element in position C3 can be seen in Fig. 5. The corresponding value of the buckling is given as

$$B_{ax}^2 = 52.13 \pm 2.02 \cdot m^{-2}.$$

The flux distributions measured in rows C and 3 are shown in Figs. 6,7 and 8. The position of the wires was 100 mm above the bottom of the core. The corresponding buckling values are

$$B_C^2 = 64.0 \pm 3.20 \quad m^{-2}$$

$$B_3^2 = 92.54 \pm 3.85 \; m^{-2}$$

$$B^2 = B_{ax}^2 + B_C^2 + B_3^2 = 208.7 \pm 5.4 \quad m^{-2}.$$

5.3 Reactivity Worth of Various Reactor Elements

Measurements were performed to evaluate the reactivity worth of the control rods and fuel blocks yielding the values of Tables 3. and 4. respectively. /The values of reactivity worth are given not only for the removal of a fuel block, but also for its exchange for graphite or paraffine./

Table 3

Reactivity worth of control rods

Rod	*Total reactivity (in ¢)*	*Reactivity/unit length (in ¢/cm)*
Manual	*0,67*	*2,00*
Automatic	*0.98*	*3.36*
Safety 1	*1.62*	*-*
Safety 2	*1.88*	*-*

prompt neutron lifetime for the core without reflector

$$\ell_C = 3.5 \cdot 10^{-5} \text{ sec},$$

and a neutron lifetime for the reflector

$$\ell_R = 1.8 \cdot 10^{-4} \text{ sec}.$$

Taking the reflector-neutrons as a delayed neutron group, the corresponding group parameters are:

$$\beta_R = 0.21 \text{ and } \lambda_R = 5.6 \cdot 10^3 \text{ sec}^{-1}.$$

6. REACTOR SAFETY

6.1 Nuclear Runaway

The kinetic behaviour of ZR-4 is very similar to that of the AGN-201 system, therefore a nuclear runaway may cause the same effect. According to the Hazard Summary Report for the AGN-201 [12] for a 2% step increase in reactivity /2.67 \$/ about 1.7 M joules is calculated to be released, which heats the core to about 71^{o}C. The peak power is about 54 MW.

Water in the gaps of fuel element would cause an increase of reactivity about 1 \$. This was measured by simulating the water by lucite plates in one fifths part of the core and extrapolating to the whole volume of the core.

More reactivity may be released by mechanical compression of the core, but for that enormous force would be necessary which is very improbable.

6.2 Health Physics Measurements

Studies were carried out for the quantitative determination of the gamma- and neutron radiation doses of the core of ZR-4; of the contamination by fission products in the air of the hall and for the qualitative and quantitative determination of some isotopes. Further we have studied after the shut-down of the reactor the variation with the time of the fission products diffusing into the air through the surfaces of the fuel elements.

The health physics investigations partly were made necessary by the fact that the ZR-4 fuel elements were made with polyethylene covering. The following health physics measurements were carried out during the operation of ZR-4 at a power of 2 W.

1./ Gamma radiation, fast and thermal neutrons were measured by a RUP-type instrument, the neutron dose by a DN-A-1 type neutron dosimeter suitable for the measurement of neutron doses over an energy range from the thermal energy up to 20 MeV. /For the calibration of the instruments Co^{60} and Pu-Be sources were used./

The results of the measurement are given in Table 5. The sketch of the hall entrance and the arrangement of the core protection wall is shown in Fig. 10.

The maximum permissible dose values for the above types of radiation are: 3 mr/h for gamma radiation, 10 neutron/sec/cm^2 for fast neutrons of 3-10 MeV energy, 700 neutron/sec/cm^2 for thermal neutrons or 3 mrem/h. So in the case of a power of 2 W the sum of the gamma radiation dose and the neutron dose in plane /A/ of the entrance is about 1,5 times the maximum permissible dose level.

Table 5.

	At plane /A/ of hall entrance	*At plane /B/ of hall entrance*	*At plane /C/ of protection wall inside the hall*
Gamma radiation	*2.0-2.9 mr/h*	*7.2-9 mr/h*	*36-72 mr/h*
Fast neutrons	*12-20* $n_f/cm^2 sec$	*40-70* $n_f/cm^2 sec$	*200-400* $n_f/cm^2 sec$
Thermal neutrons	*420-600* $n_t/cm^2 sec$	*800-2000*$n_t/cm^2 sec$	*3000-5000*$n_t/cm^2 sec$
Neutron dose rate	*2-3 mrem/h*	*5-10 mrem/h*	*20-50 mrem/h*

2./ For testing the radioactive contaminations in the air a FPP-5 type fibrous filter and a granulated active charcoal filter were used [13], through which air in a quantity of 3 m^3/h was pumped by a vacuum-pump during 3 hours. The filters were placed behind the protection wall.

The activity of the aerosols on FPP-15 type filter were measured with beta and gamma scintillation detectors.

Radioactive vapours and some gaseous materials were measured by the activated charcoal filter. For the measurements a 10 cm^3 Ge/Li/ semiconductor detector with a resolution of 5,6 keV for 123 keV of Co^{57} and of 8,8 keV for Co^{60}, further a 4K type analyzer made in our Institute on the one hand, and a

NaI/Tl/ scintillation detector with a resolution of 8,5 % for Cs^{137} and a NTA-512 type analyzer also made in our Institute on the other hand were used. For the calibration of the measuring units Na^{22}, Mn^{54}, Co^{57}, Co^{60}, Te^{123}, I^{131}, Hg^{203}, and U_3O_8 were used.

Points of air sampling were:

a./ Mid-core at the position of fuel elements B3 or C3. Sample No 1.

b./ At 20 cm above the core. Sample No 2.

c./ At a distance of 200 cm from the core. Sample No.3.

d./ ZR-4 hall /background with the reactor shut-down/. Sample No.4.

Tables 6. and 6/a. show the radioactive concentration for gamma, beta /aerosol/, I^{131}, I^{133}, I^{135} and Xe^{135} at the sampling points.

Table 6

Radioactive concentration in the air at 2 W.				
γ-radiation ($\mu Ci/cm^3$)			*β-radiation ($\mu Ci/cm^3$) (aerosol)*	
Mid-core (Sample No.1.)	*20 cm above core (Sample No.2.)*	*200 cm from core (Sample No.3.)*	*Mid-core (Sample No.1.)*	*20 cm above core (Sample No.2.)*
$1.1\cdot 10^{-6}$	$1.3\cdot 10^{-9}$	$0.5\cdot 10^{-9}$	2.10^{-8}	$1.5-10^{-10}$

Table 6/a

Radioactive I^{131}, I^{133}, I^{135} and Xe^{135} concentration in air at 2 W ($\mu Ci/cm^3$) Sample No.1.			
I^{131}	I^{133}	I^{135}	Xe^{135}
2.10^{-9}	$2.9\cdot 10^{-9}$	$2.6\cdot 10^{-9}$	$0.8\cdot 10^{-7}$

Background of ZR-4 hall with the reactor shut-down $0.32\cdot 10^{-9}$ $\mu Ci/cm^3$. Sample No.4.

The maximum permissible concentration values according to the valid standard specification No. MSZ-62-61 and the regulation of the Ministry of Health No. 22/1966 are:

for fission products	$1 \cdot 10^{-9}$	$\mu Ci/cm^3$
" I^{131}	$3 \cdot 10^{-9}$	"
" I^{133}	$3 \cdot 10^{-8}$	"
" I^{135}	$1 \cdot 10^{-7}$	"
" Xe^{135}	$1 \cdot 10^{-6}$	"

The above data show that the radioactive concentrations of the air sampled at a distance of 200 cm from the core and at 20 cm above the core are near to the concentrations permissible for fission products, while the I^{131}, I^{133}, I^{135}, and Xe^{135} concentrations are even within the core below the maximum permissible concentration values.

Further we have studied the gamma spectra of air sampled in the middle of the core, at 20 cm above the core and of wipe samples taken from the 400 cm^2 surface of a fuel element. Table 7. contains the energy spectra of the individual samples showing that the values 530 keV, 656 keV, 890 keV and 1460 keV are to be found in all three samples. On the basis of our investigations we were able to identify the isotopes I^{131}, I^{133}, I^{135} and Xe^{135}. In order to identify the isotopes belonging to the other energies further studies are needed. In Table 7. x denotes the presence of an energy peak in the studied samples.

Figs. 11, 11/a and 11/b show the gamma spectrum of the air sampled from the midcore /sample No.1./ 5 hours after the sampling. In Fig. 12. the gamma spectrum of the same sample contains the peak energies of I^{131} and the 530 keV value of I^{133}, 5 days after the sampling.

Fig. 13. shows the half-life measurement of the 250 keV and 530 keV energy peaks. The half-lifes resulted as 9^h at 250 keV and as $20,5^h$ at 530 keV, by which the presence of Xe^{135} and I^{133} can be established.

Fig. 14. shows the /beta/ decay of the aerosol sample /a_1/ and the gamma activity decay of the activated charcoal sample /a_2/. The figure shows rather well that the activity of the aerosol sample decreased to less than 1 % and that of the activated charcoal sample to 5 % 20 hours after the sampling.

Fig. 5. shows the gamma activity variation of air samples taken on activated charcoal at intervals of 16 minutes in the middle of the core after shutting down a 3 hour—run of ZR-4. The measurement on every sample started

Table 7

Gamma energy spectra of the samples			
MeV	Midcore	20 cm above the core	Wipe sample from the 400 cm^2 surface of the fuel element
0.167	-	-	x
0.220	x	-	-
0.250	x	-	-
0.287	x	-	-
0.339	-	-	x
0.418	x	x	-
0.460	-	x	x
0.530	x	x	x
0.543	x	-	-
0.555	-	-	x
0.614	x	-	-
0.656	x	x	x
0.710	x	-	-
0.755	-	-	x
0.768	-	x	x
0.773	x	-	-
0.843	x	-	
0.890	x	x	x
0.941	-	x	x
0.967	-	x	x
0.980	x	-	-
1.028	-	x	x
1.045	x	-	-
1.136	x	-	
1.264	x	-	
1.387	-	x	
1.430	-	-	x
1.460	x	x	x
1.678	x	-	-
1.707	x	-	-
1.790	x	-	-
1.824	x	-	-
1.858	x	-	-
2.030	x	-	-
2.230	x	-	-
2.386	x	-	-

5 minutes after the sampling. It is seen that 3 hours after the shut-down the gamma activity of the fission products diffused through the polyethlylene covering of the fuel elements decreased to 16 %.

We have also examined the contamination of the wipe sample taken from the surface of the fuel element. 10 minutes after the shut-down of a one-hour run 7-10 times of the maximum permissible contamination for fission products could be measured /RUP-1/.

From our investigations it could be concluded that the radioactive concentration of the air sampled at 20 cm above the core /Table 6./ was by nearly 3 orders of magnitude less than that of the air sampled from the inside of the core, i.e. it fell into the order of magnitude of the background. Further the concentrations of some isotopes such as I^{131}, I^{133}, I^{135} and Xe^{135} in the air sampled from the inside of the core were also below the maximum permissible concentration and if we take into consideration the volume of the hall and the threefold air exchange per hour too, we can state, that in the case of operating ZR-4 at 2 W the values measurable in the air of the hall are below the maximum permissible values.

The measurable values of the gamma radiation, fast and thermal neutrons and neutron doses in plane /A/ of the hall entrance are also below the permissible maximum dose levels, so in case of the operation of ZR-4 at 2 W. the presently realised protection secures the working conditions, if the prescribed work-regulations are observed.

7. RESEARCH PROGRAM

Research activities planned in connection with the ZR-4 zero power reactor can be divided into following groups:

- experimental verification of calculations,
- reactor kinetics,
- spectrum problems.

As reported in [14] extensive work is going on in order to develop a numerical basis for reactor calculations. Calculated results need to be experimentally verified. The ZR-4 has been primarily intended for this experimental verification. The basic code of these calculations is a two-dimensional few-group diffusion criticality code called SISYPHUS. Its construction allows to form cores of various shapes, its homogeneous structure eliminates heterogeneity effects, the core does not contain any control elements. These are the main features which make it especially suitable for such type of work. Of course, owing to its homogeneous structure, the ZR-4 does not lend itself for the experimental verification of cell calculations.

Besides calculations of this type, the ZR-4 shall serve for the verification of theoretical results in space-dependent reactor kinetics, too. As an example of this, a code developed for the solution of the space-time dependent one-dimensional two-group diffusion equation can be mentioned.

Other activities planned in reactor kinetics include noise studies and measurement of reactivity. As to the measurement of reactivity, investigations will be concerned with determination of subcritical reactivities using different techniques among others pulsed neutron technique. Problems connected with space dependence, such as higher harmonics, reflector effects, existence of fundamental mode in reflected systems are examples of these. Another aspect of these studies will be the comparison of reactivity determinations carried out in subcritical and supercritical states. Experiments on neutron waves, propagation of neutron bursts are planned too.

Slowing down and thermalized neutron spectra will be investigated both theoretically and experimentally. By varying the thicknesses of foils and of their covers made of suitably chosen materials, cross sections of various energy dependences can be created. This allows to get detailed information about the reactor spectrum.

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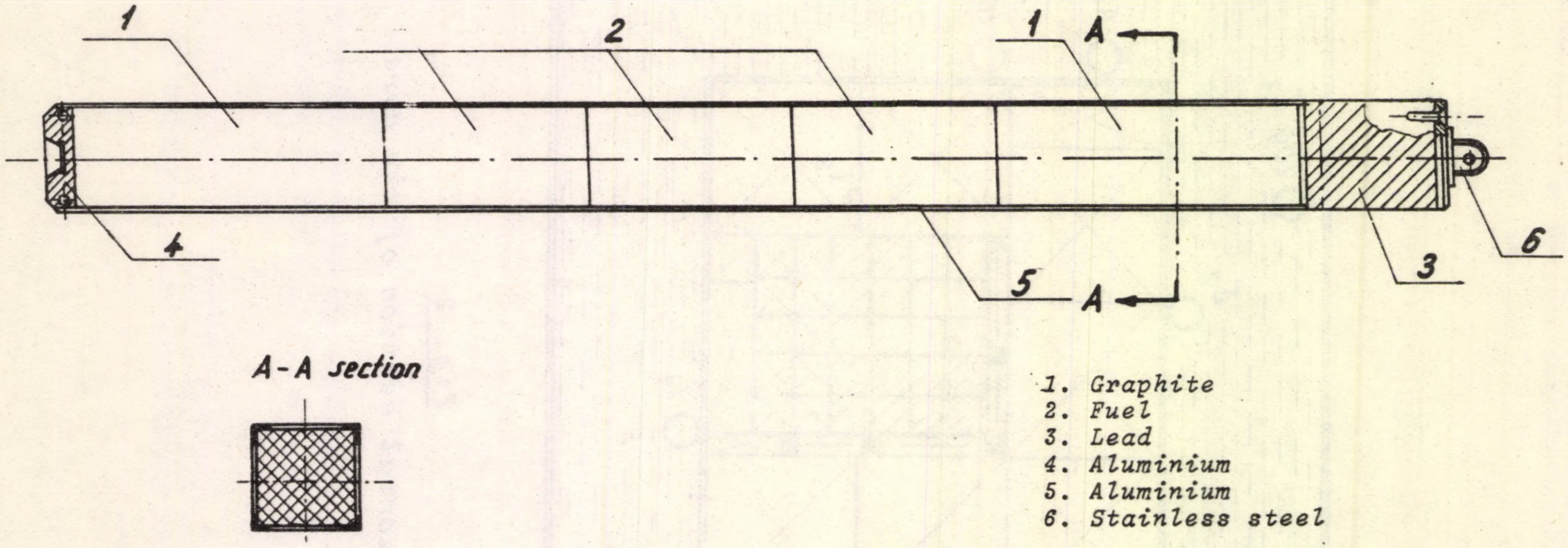

<u>*Fig. 1*</u>

Fuel element of ZR-4

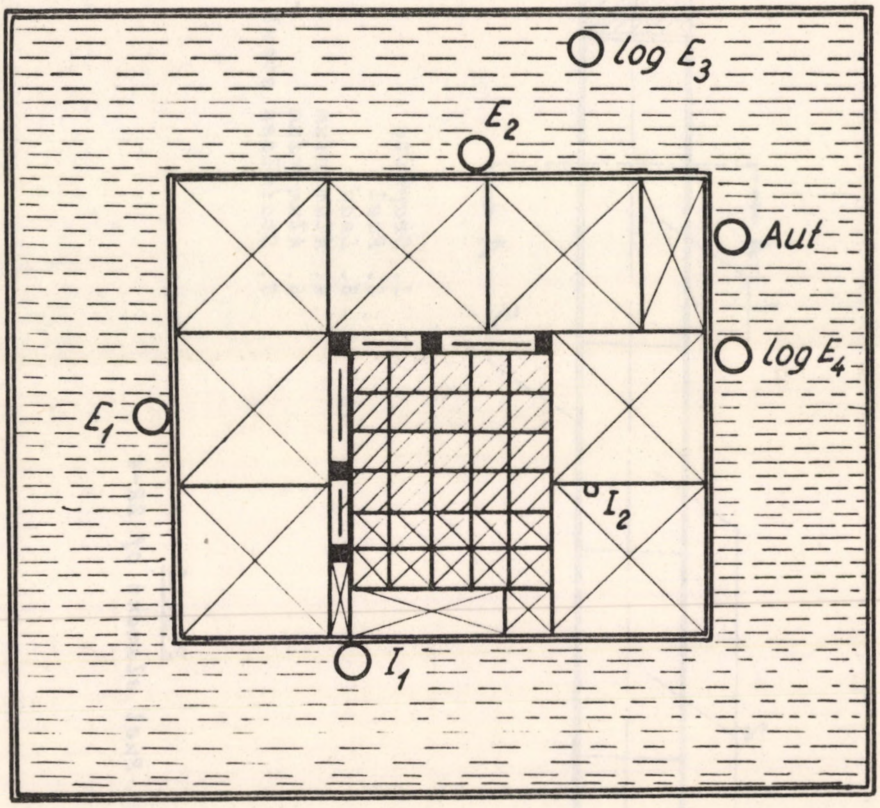

Fig. 2

Horizontal section of the core

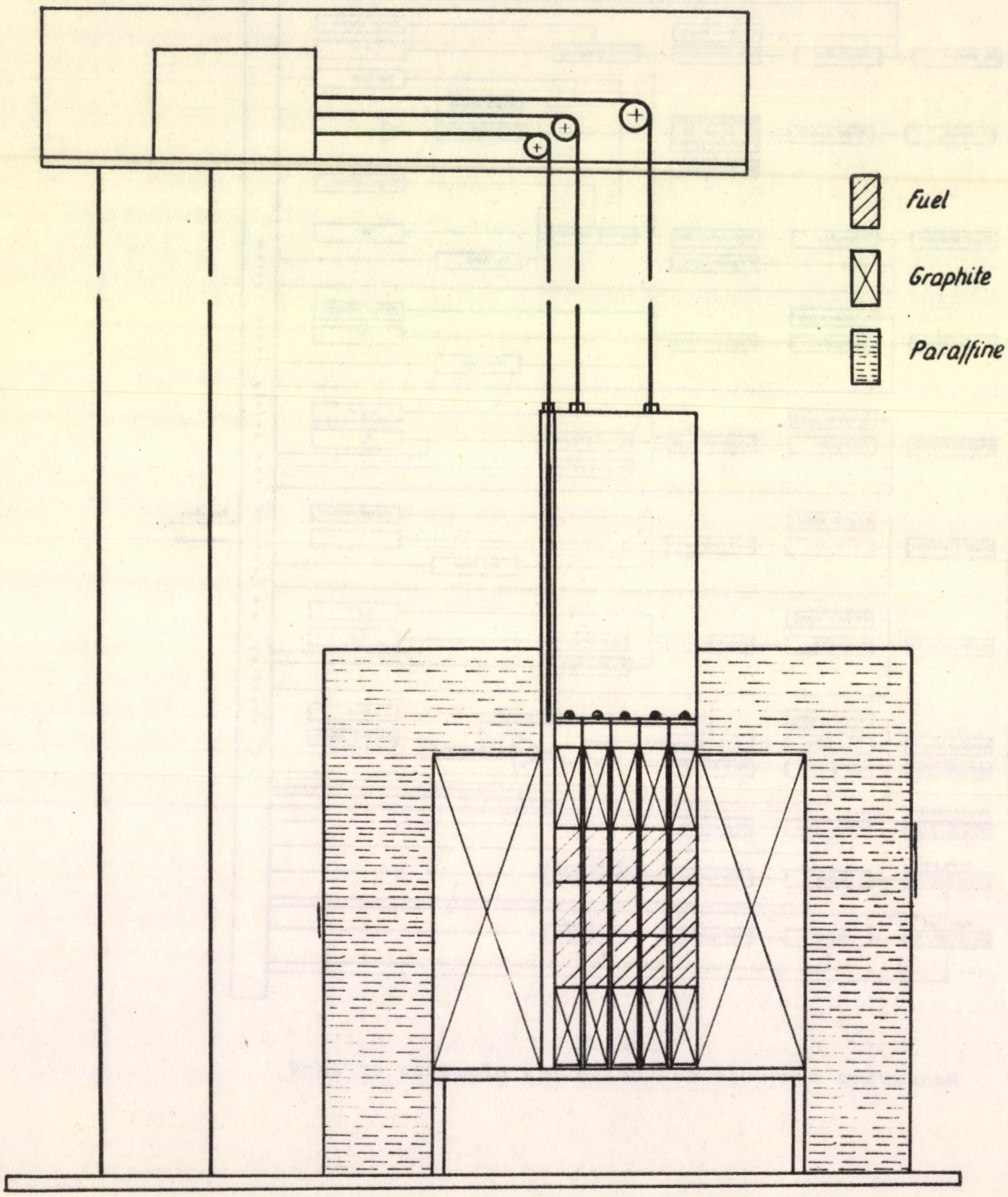

Fig. 3

Vertical section of the core

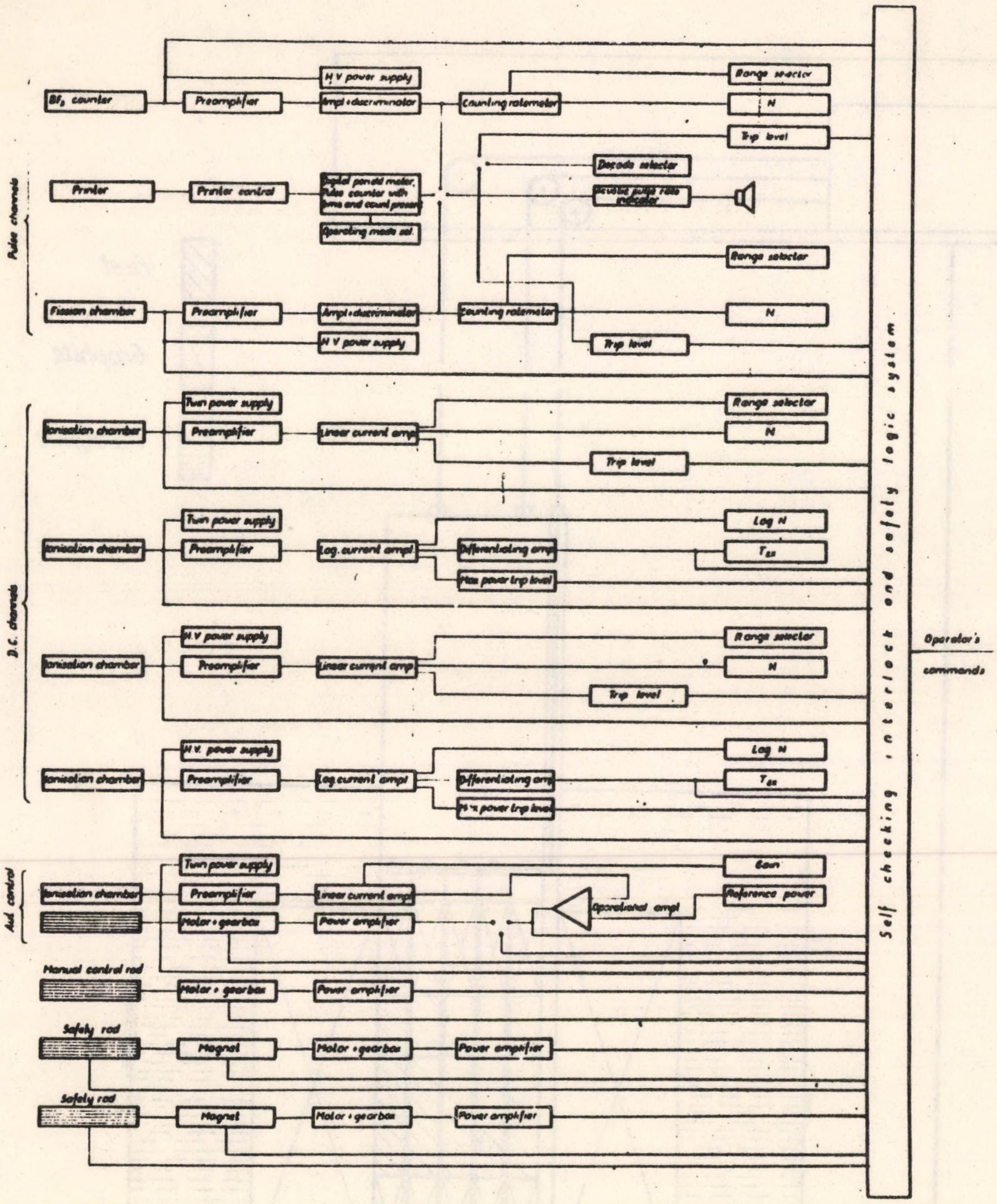

Fig. 4

Measuring channels and actuating elements of ZR-4

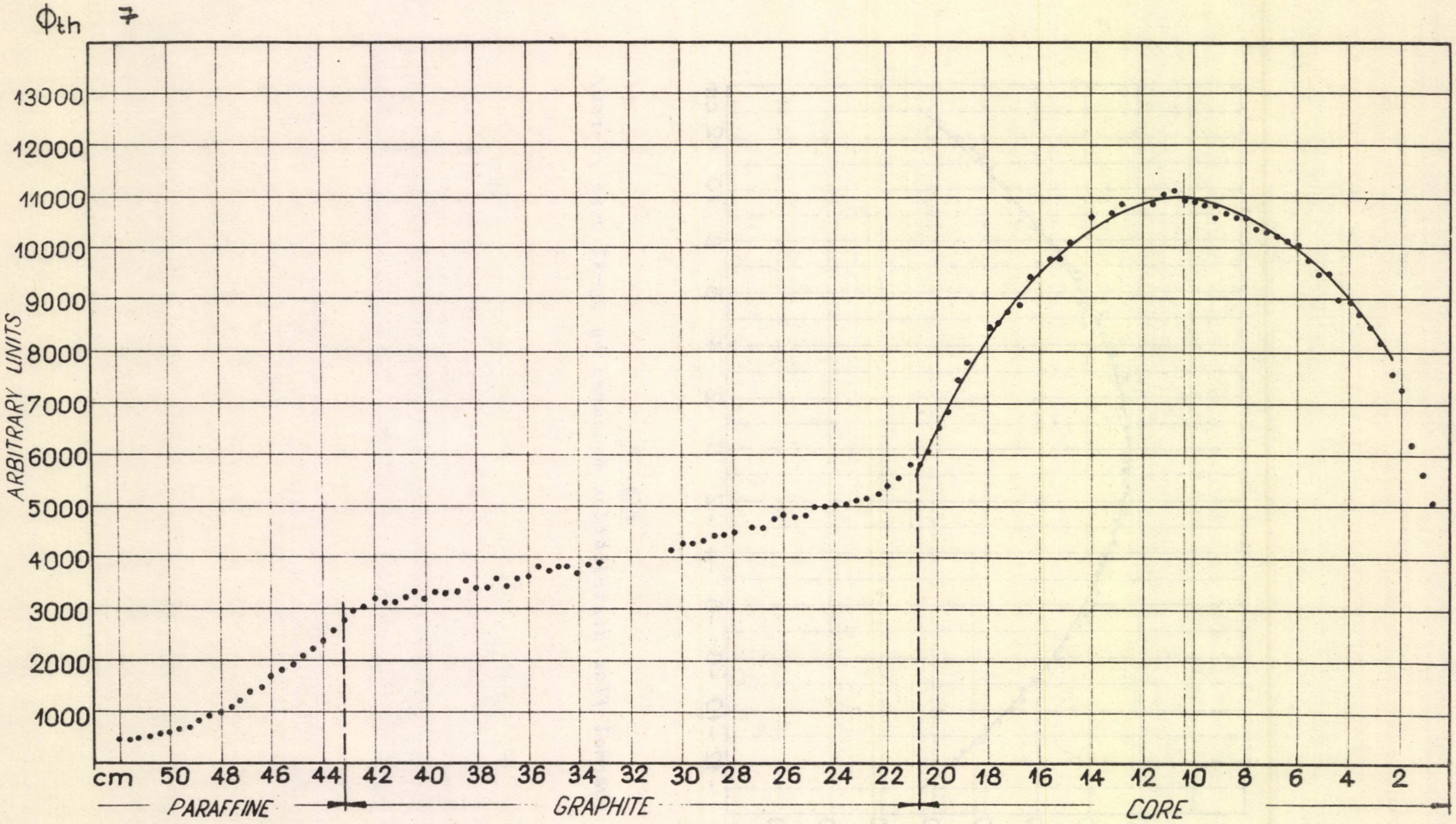

Fig. 7

Radial thermal flux distribution measured by Dy-Al wire /3-row/

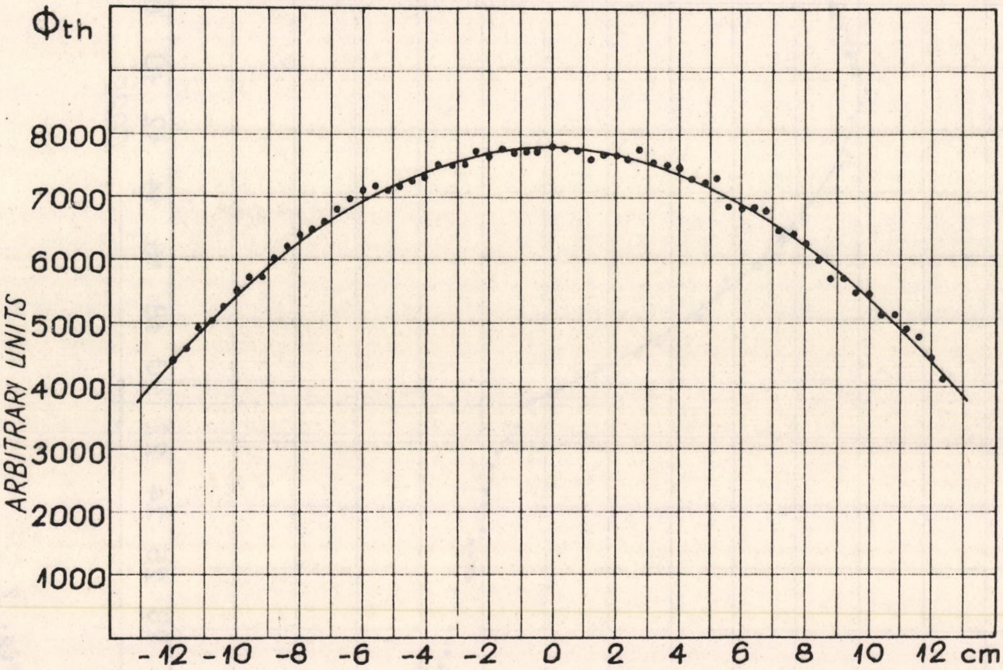

Fig. 8

Radial thermal flux distribution measured by Dy-Al wire /C-row/

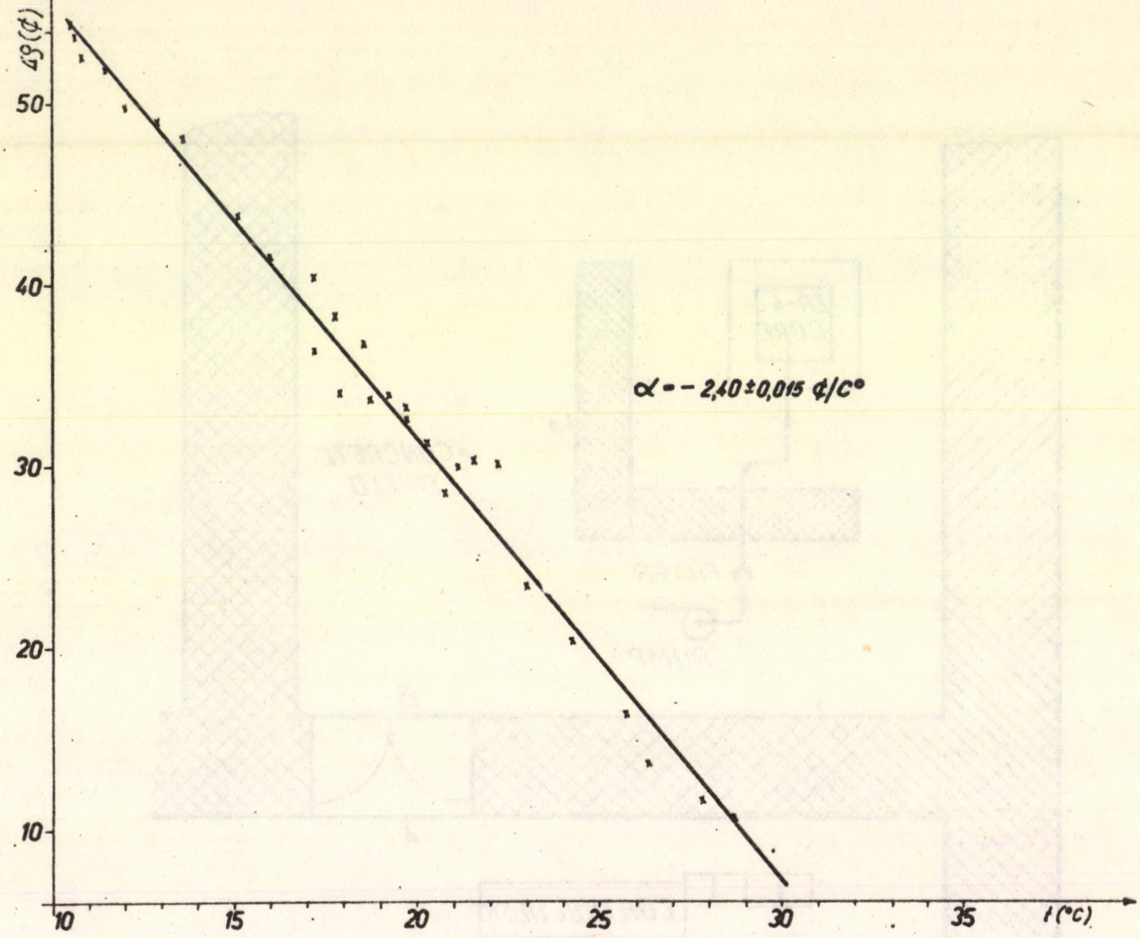

Fig. 9

Temperature coefficient of ZR-4 core

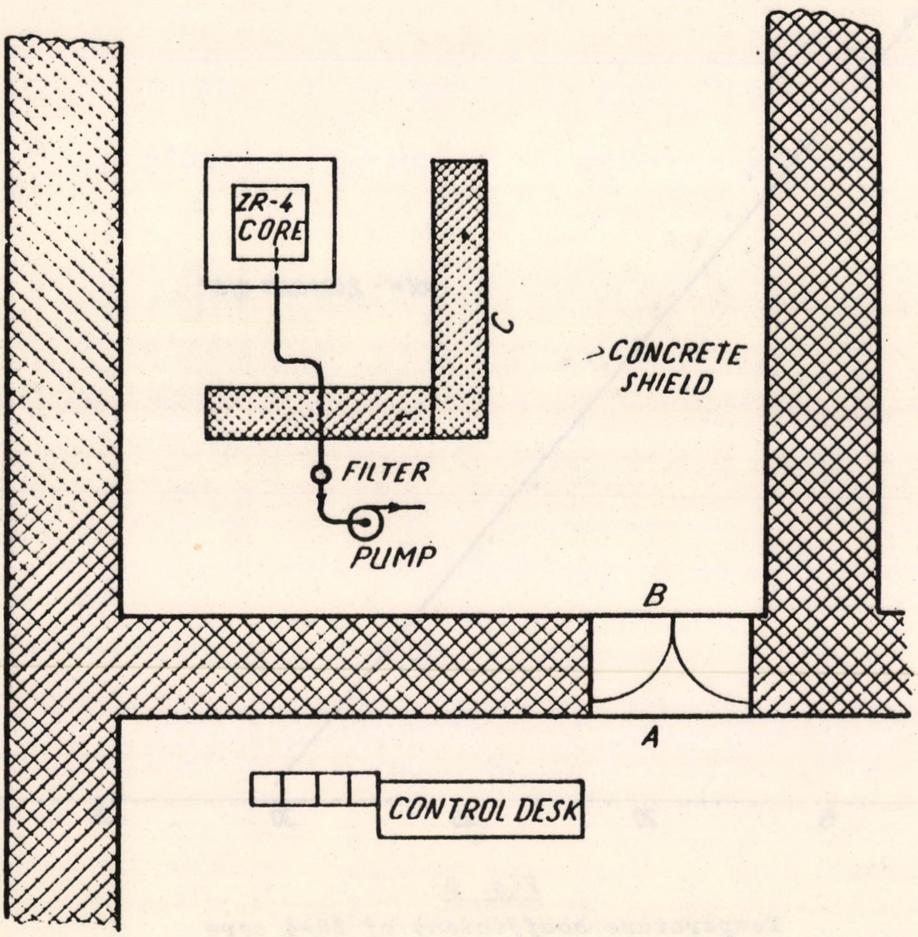

Fig. 10

Sketch of the hall entrance and arrangement of the core protection wall

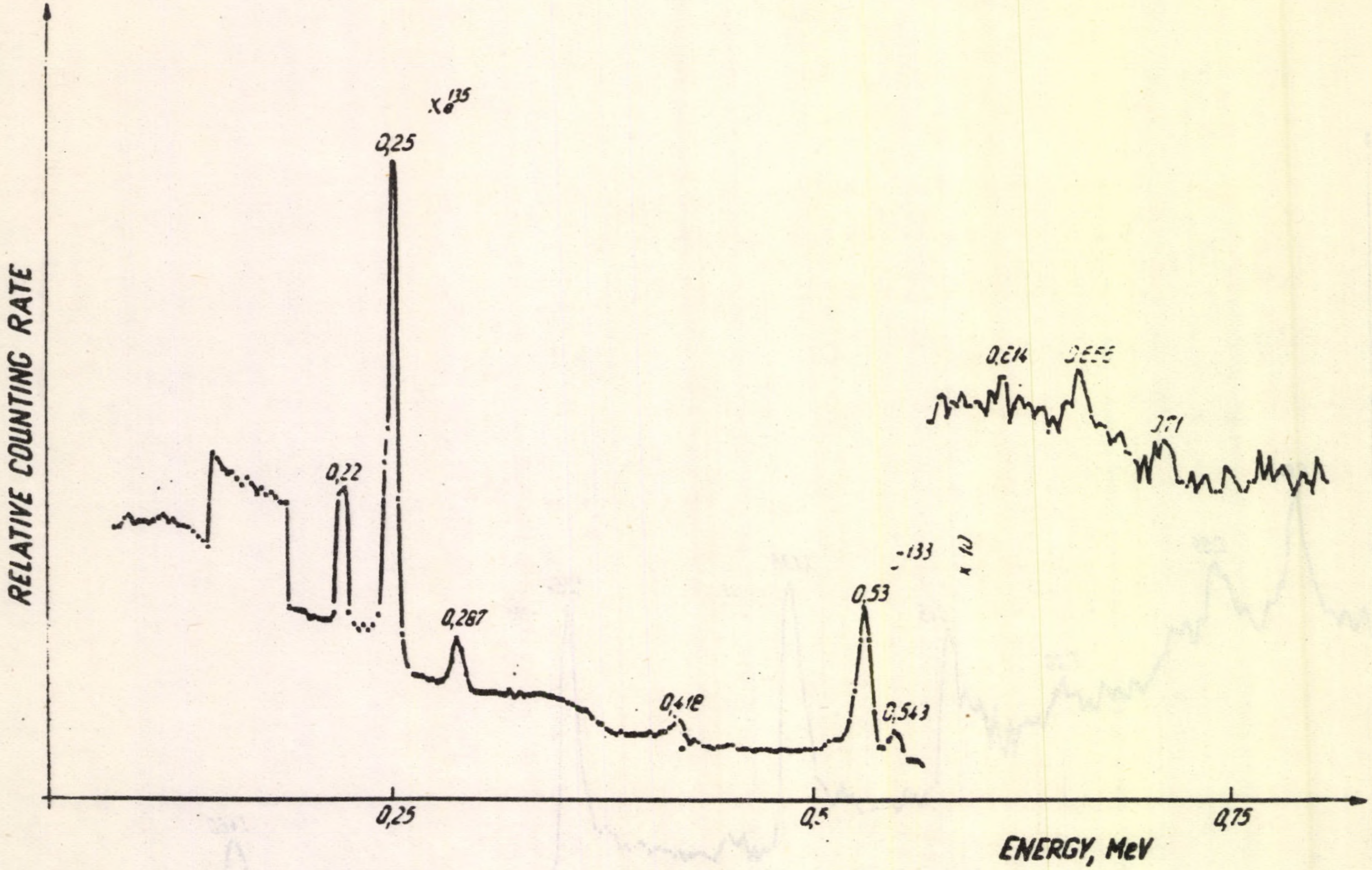

Fig. 11

Gamma spectrum 5 hours after taking of air sample No.1.
from the core of ZR-4

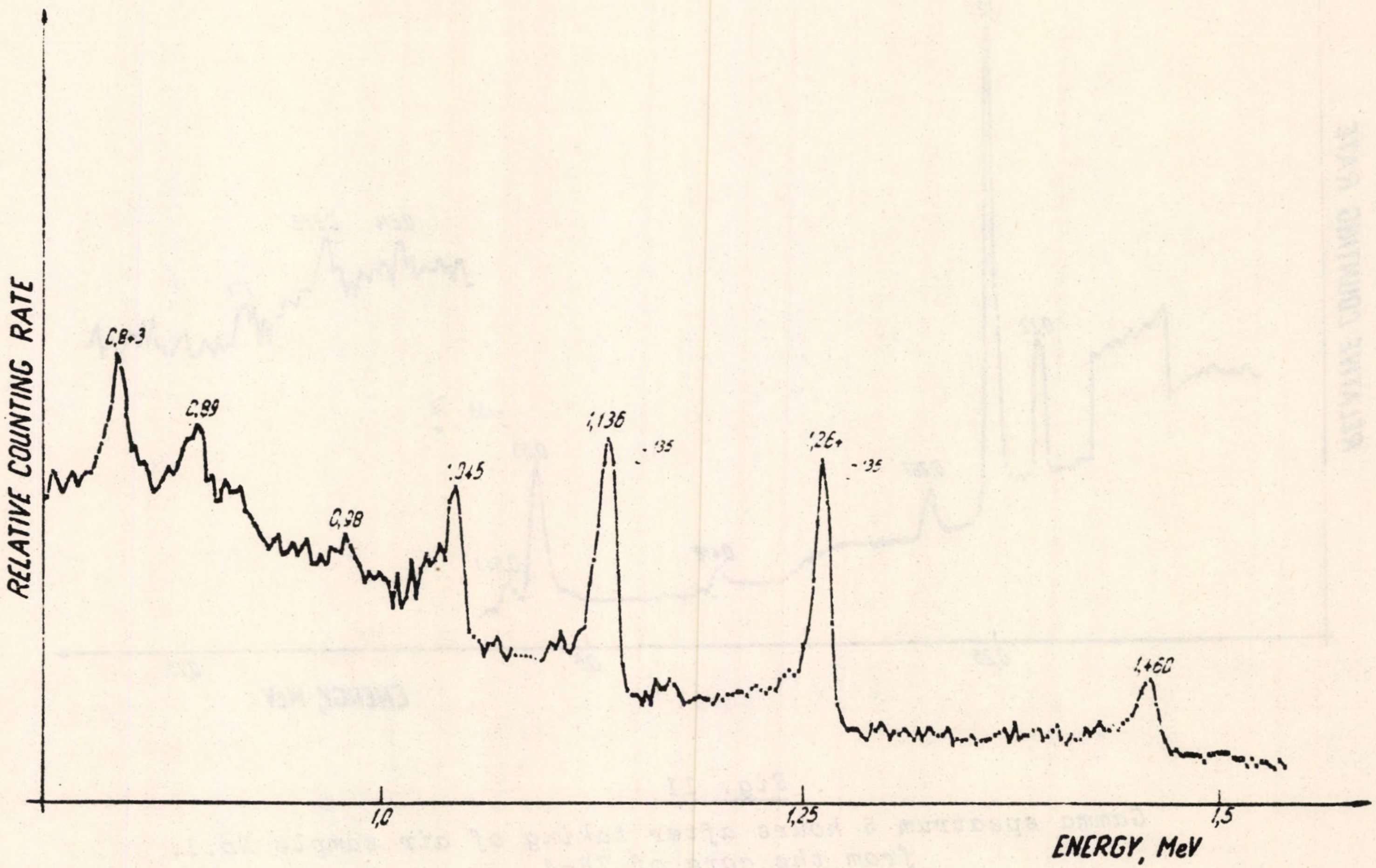

Fig. 11/a

Gamma spectrum 5 hours after taking of air sample No.1. from the core of ZR-4

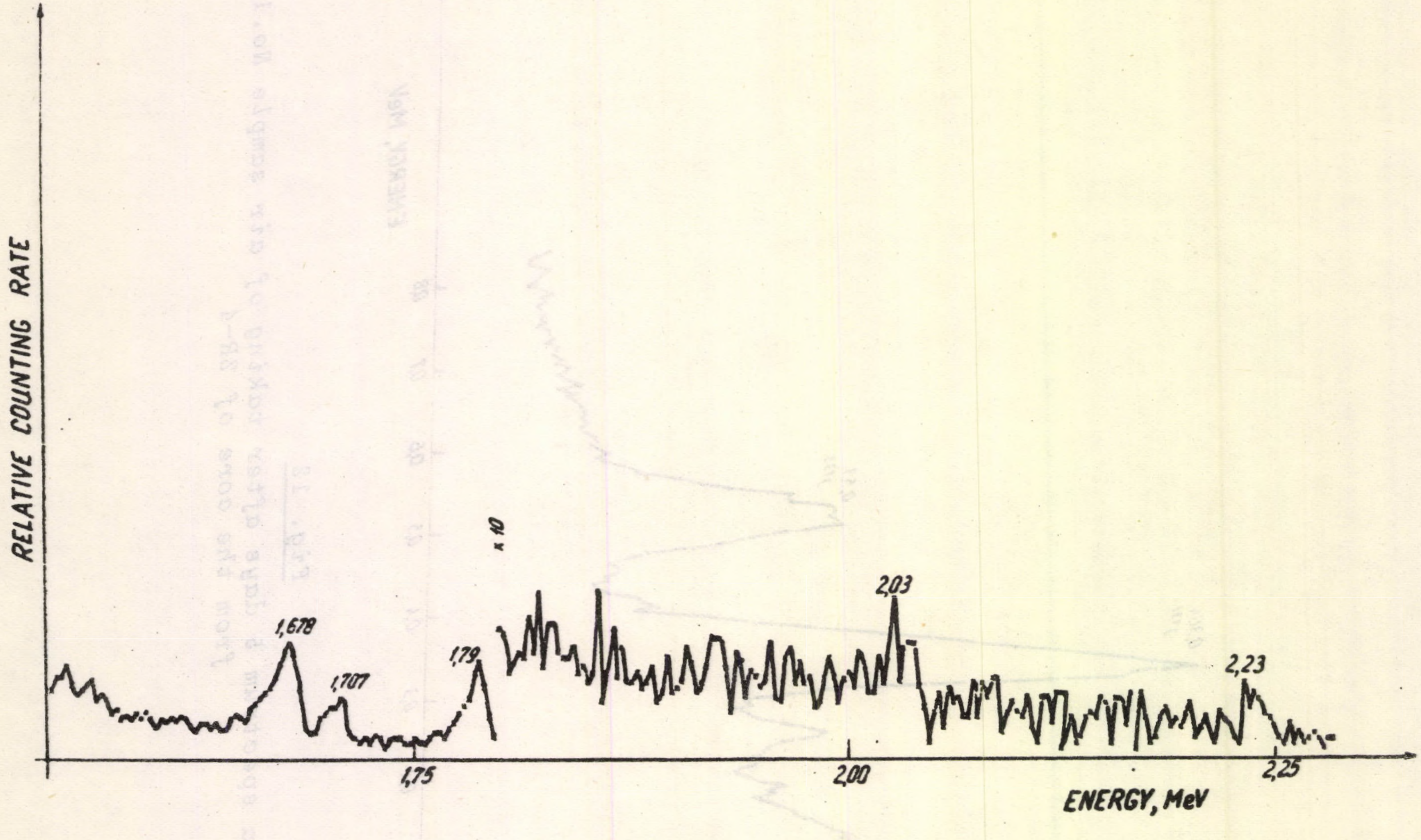

Fig. 11/b

Gamma spectrum 5 hours after taking of air sample No.1. from the core of ZR-4

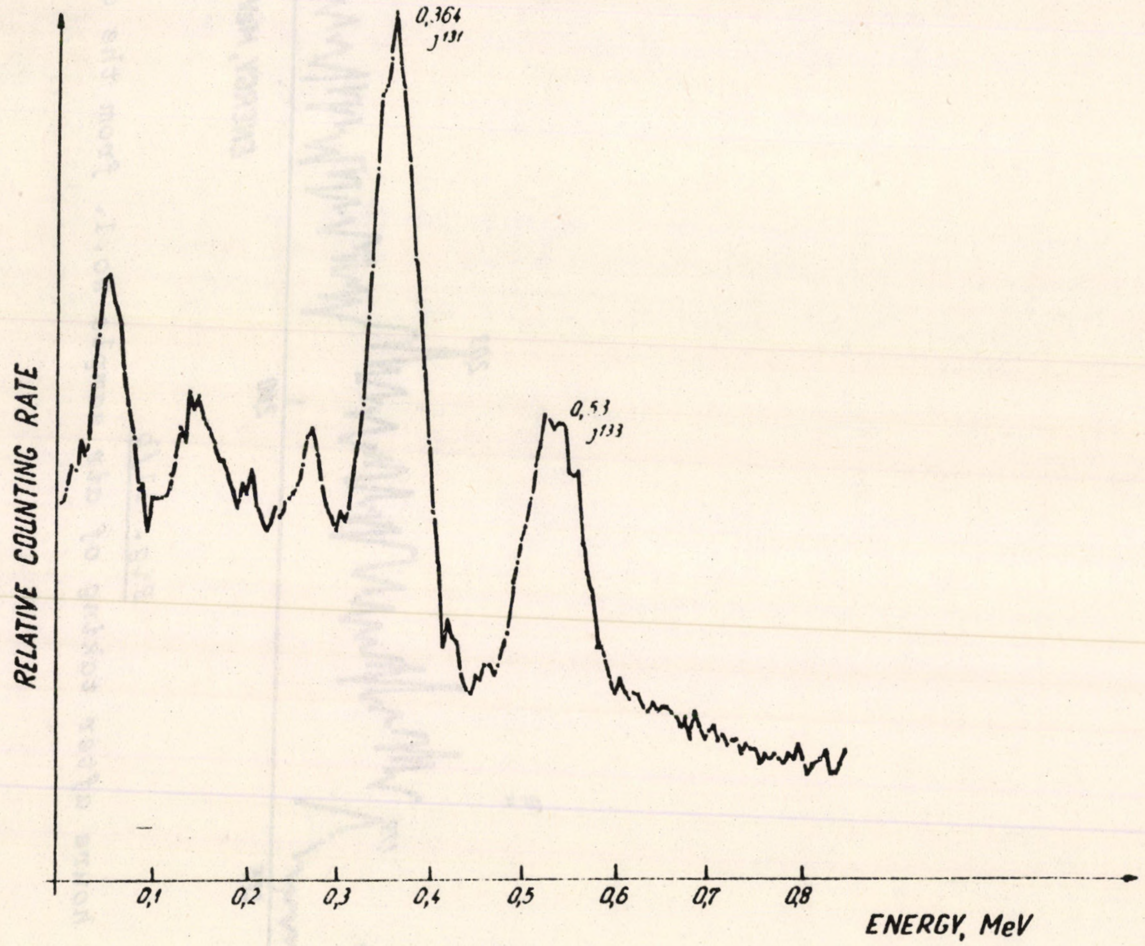

Fig. 12

Gamma spectrum 5 days after taking of air sample No.1. from the core of ZR-4

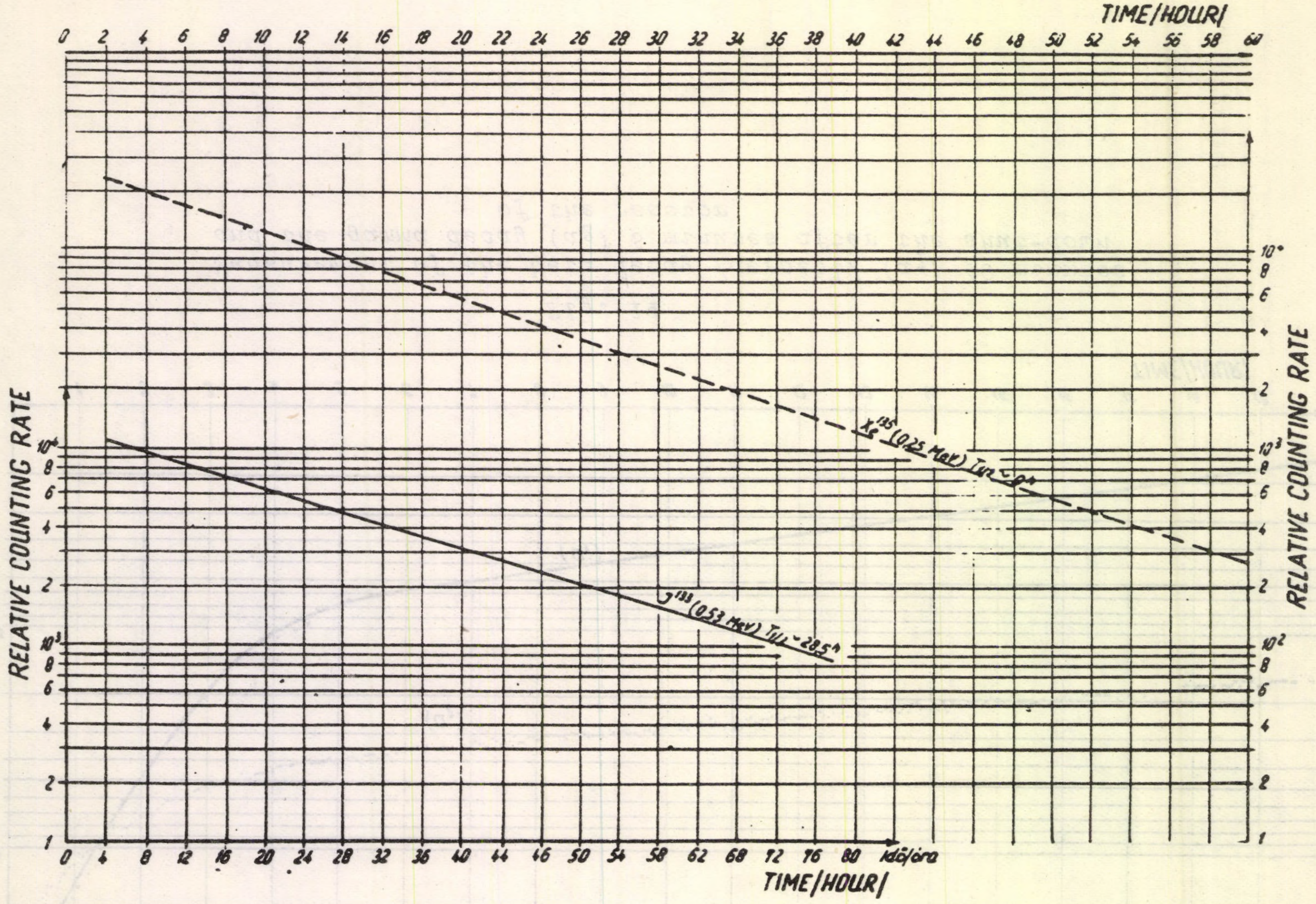

Fig. 13

Measurement of the half-life of I^{133} /530 keV/ and of Xe^{135} /250 keV/

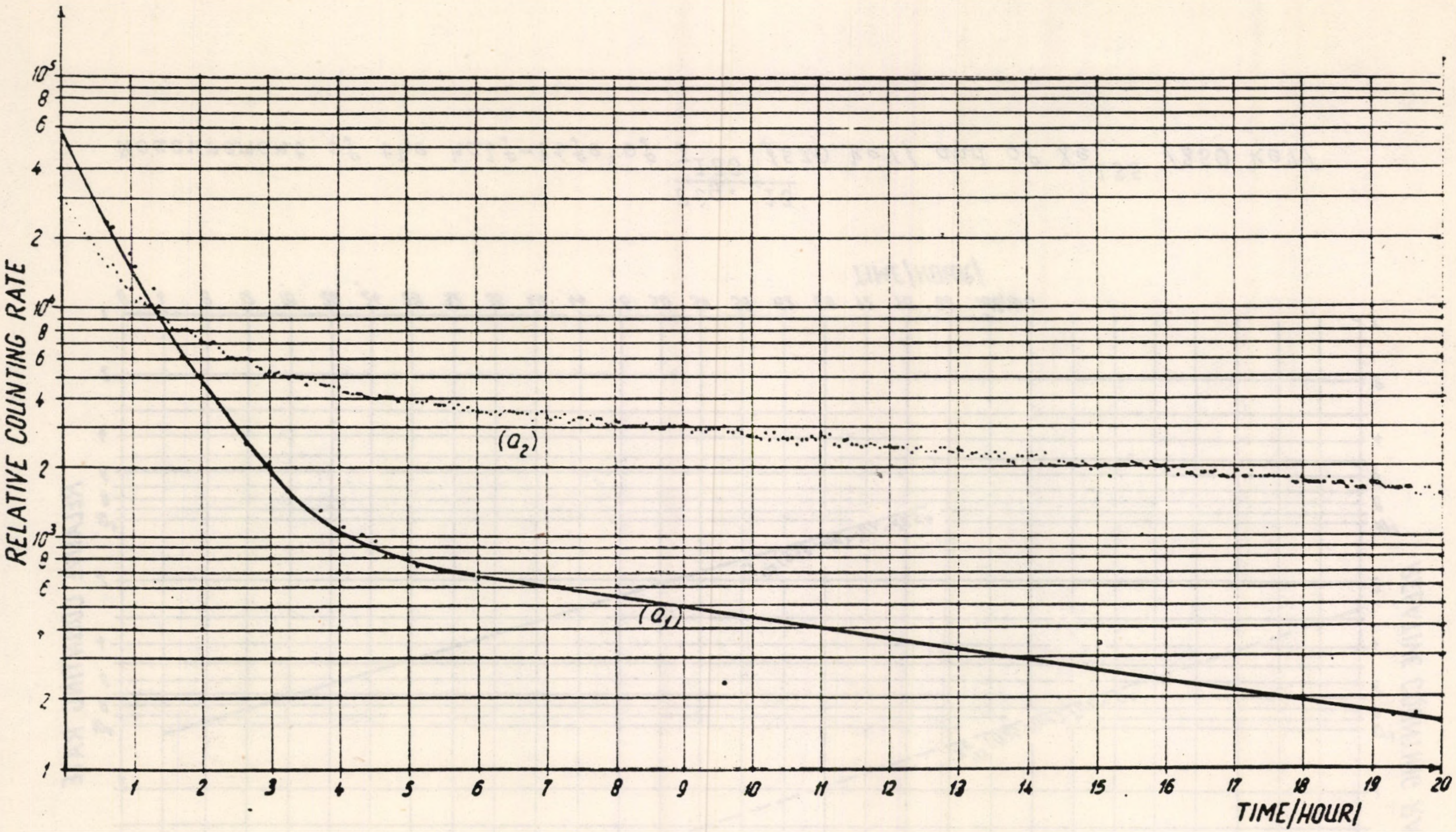

Fig. 14

Measurement of the beta decay /aerosol/ (a_1) 40 minutes and the gamma decay (a_2) 5 minutes after the shut-down of the reactor

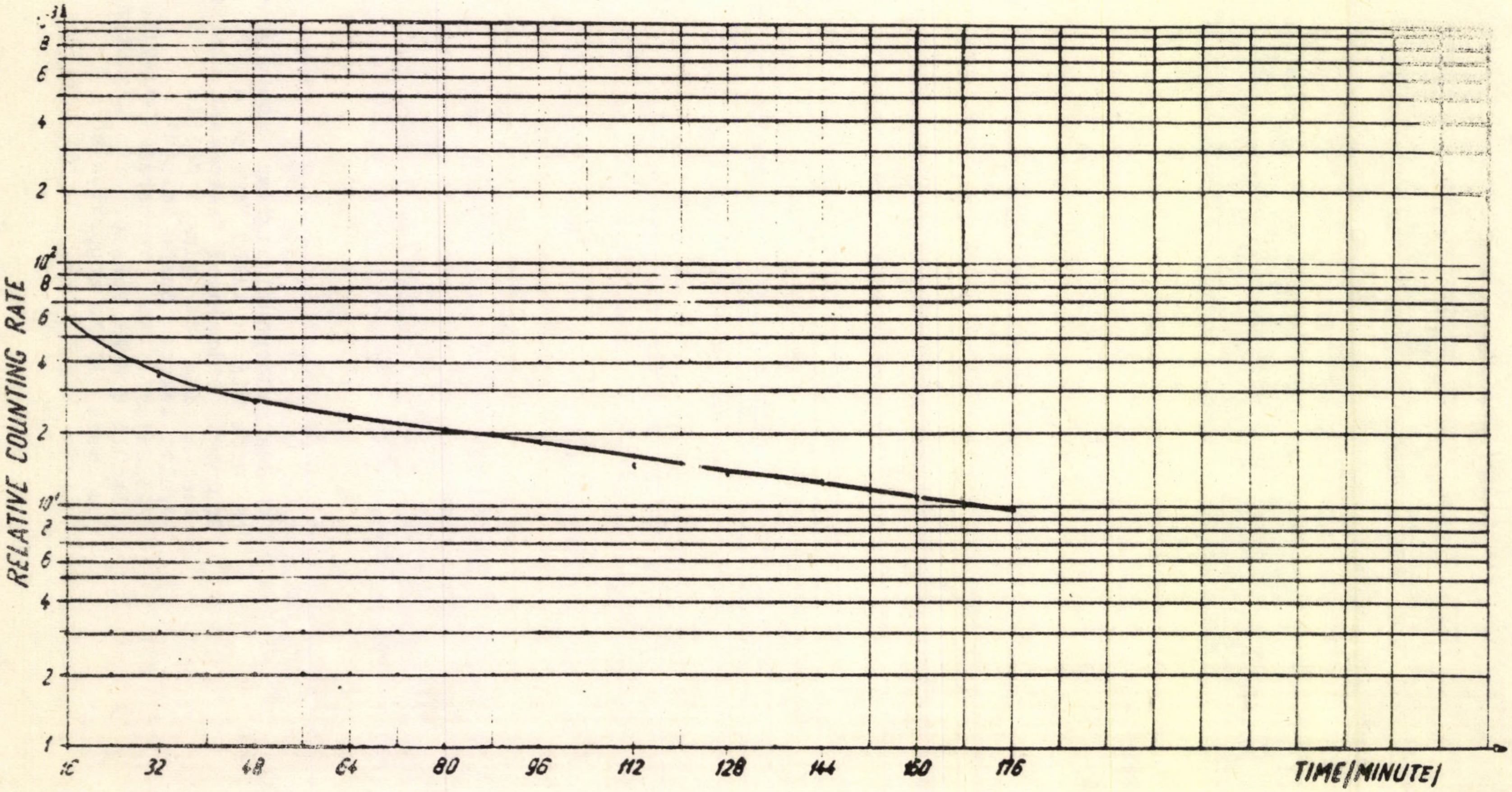

Fig. 15

Gamma activity of air sampled from the core at intervals of 16 minutes after the shut-down of the reactor

61.976

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Budapest, 1972. augusztus hó